Utility-Scale Distribution-Connected PV in Southern California: Modeling and Field Demonstration Results

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Integrating PV in Distribution Grids: Solutions and Technologies

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NREL/SCE Hi-Pen PV Integration Project

5 MW Fixed-Tilt Ground-Mount System near Porterville, CA

2 MW Warehouse Roof Mounted PV System near Fontana, CA

- Impetus – in 2009 SCE received approval to install 500 MW of distribution-connected PV in their service territory
- Focus – developing new “rules of thumb” for utility planning engineers for interconnecting large (1-5MW) PV systems on medium voltage (MV) distribution circuits and developing methods to reduce the PV impacts on these systems
- Goal – easing the interconnection concerns of utilities faced with utility-scale distribution-connected PV systems, enabling utility engineers to correctly assess a PV systems potential circuit impacts, and demonstrating that there are current methods for mitigating the impacts of high-penetration PV that can be implemented in the near-term for low cost

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QUANTA TECHNOLOGY

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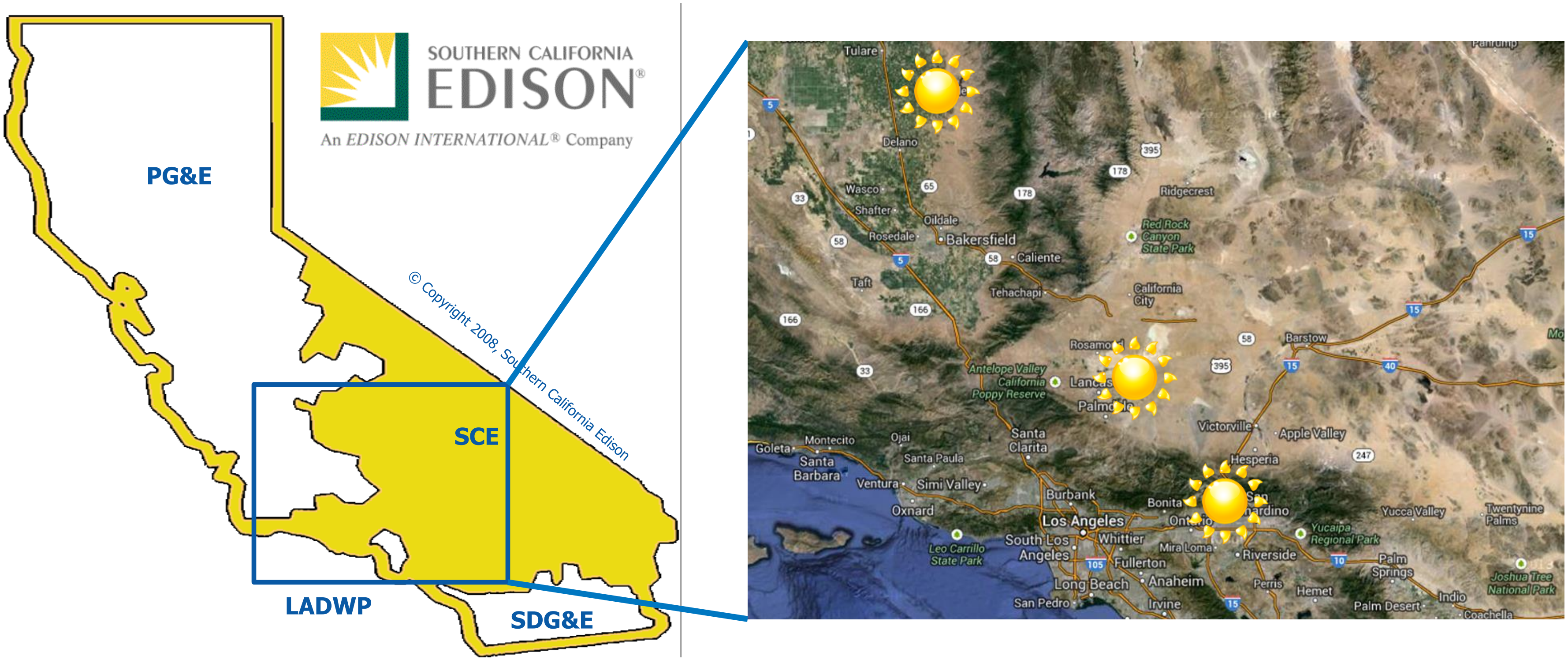
NREL/SCE Study Circuits



Fontana Characteristics:

- 4.5 MW of PV
- 2 PV systems
- 12 kV
- commercial circuit

Palmdale Characteristics:

- 3 MW of PV
- 2 PV systems
- 12 kV
- rural circuit
- extremely lightly loaded

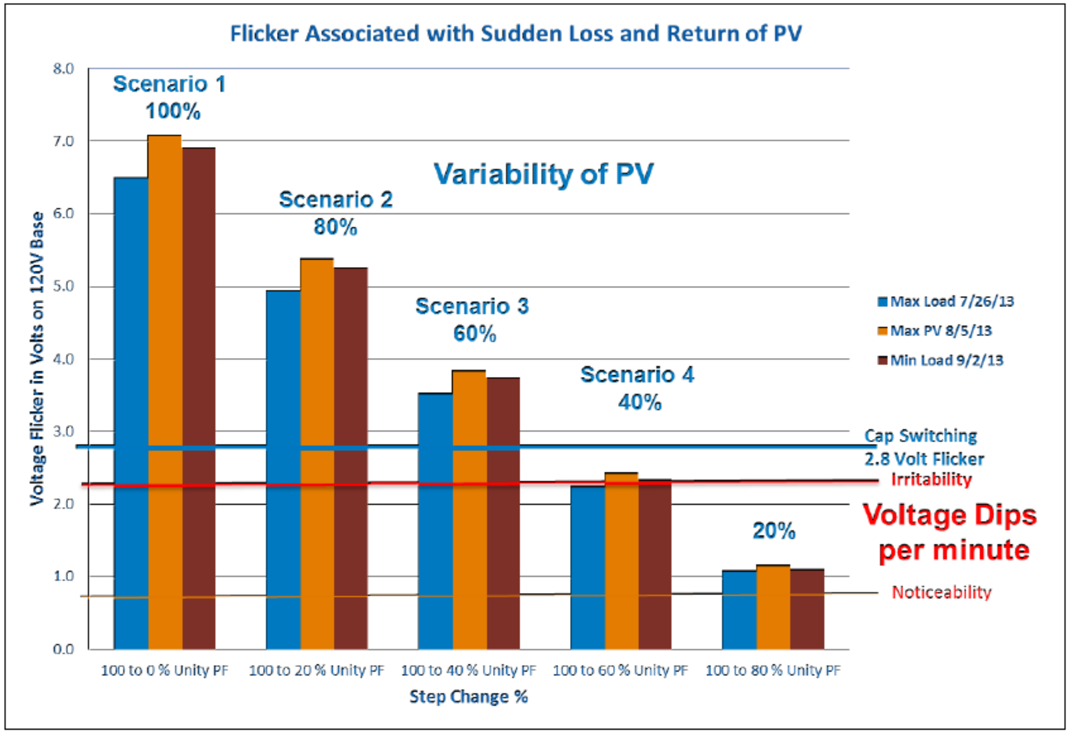
Porterville Characteristics:

- 5 MW of PV
- Single PV system
- 12 kV
- rural circuit
- 40 miles total length

Dev. of PV Impact Assessment Method

Developed a PV Impact Methodology Based on Salient Operating Points

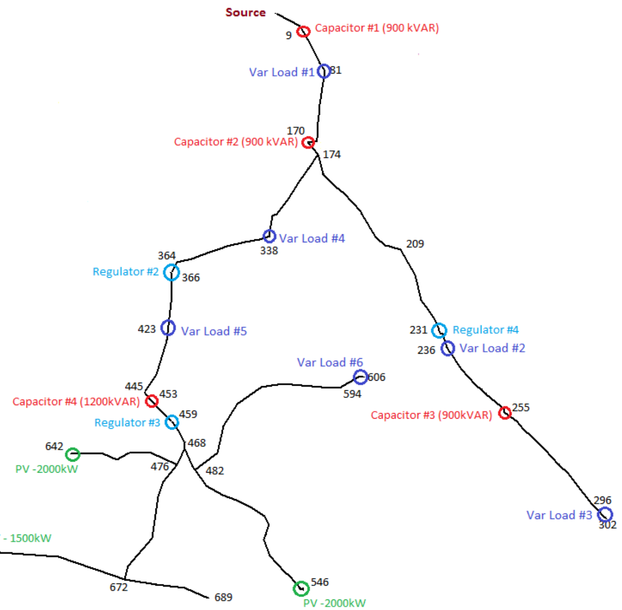
- Investigated PV impact mitigation techniques on the study circuit – utilizing advanced PV inverter functionality
- Assumed worst case PV ramping
- Investigated three loading levels
- Tried to minimize voltage variations below “Noticeability”



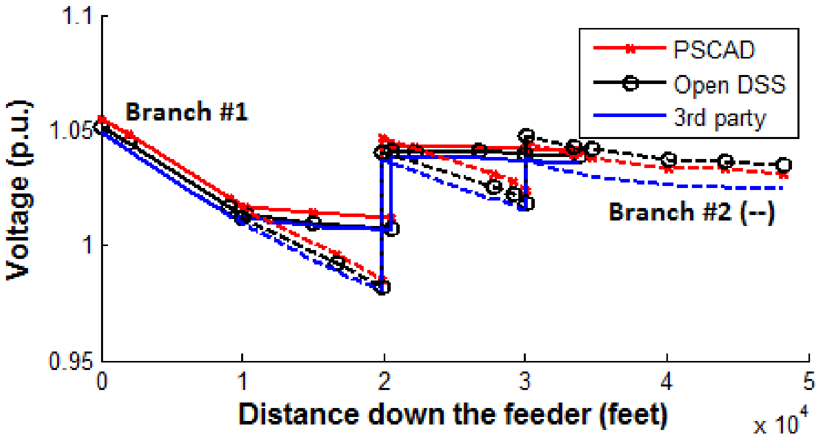
See: B. Mather, et al., *“NREL/SCE High Penetration PV Integration Project: FY13 Annual Report,”* *NREL Tech. Report TP-5D00-61269, June, 2014.*

Comparison of Quasi-Static Time-Series and Transient Simulation Analysis Techniques

IEEE 8500 node test feeder model



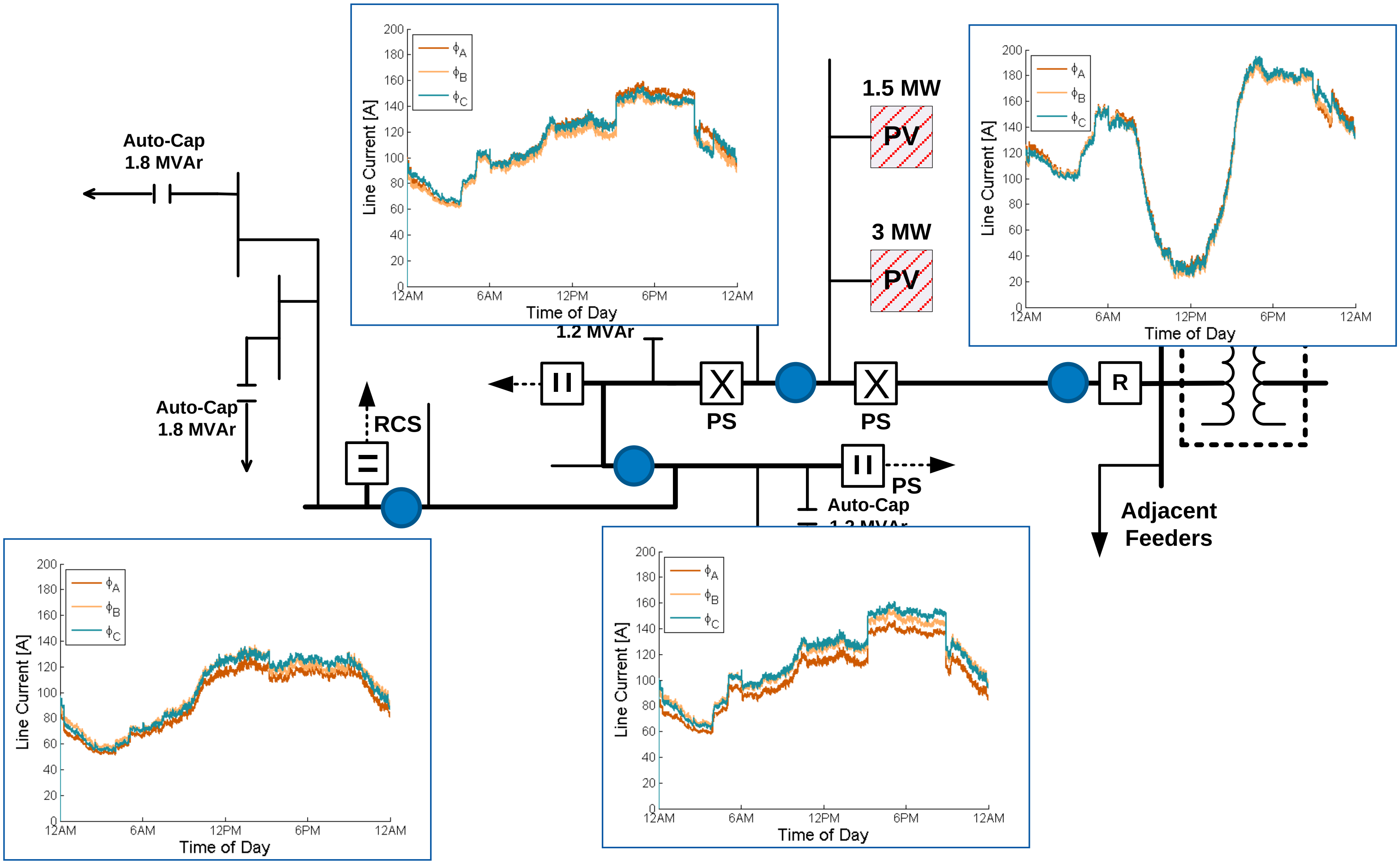
- Evaluated quasi-static time-series analysis results at multiple time steps over a 16 minute period
- Analysis run times are on the order of 5 hours for PSCAD and 5 seconds for OpenDSS



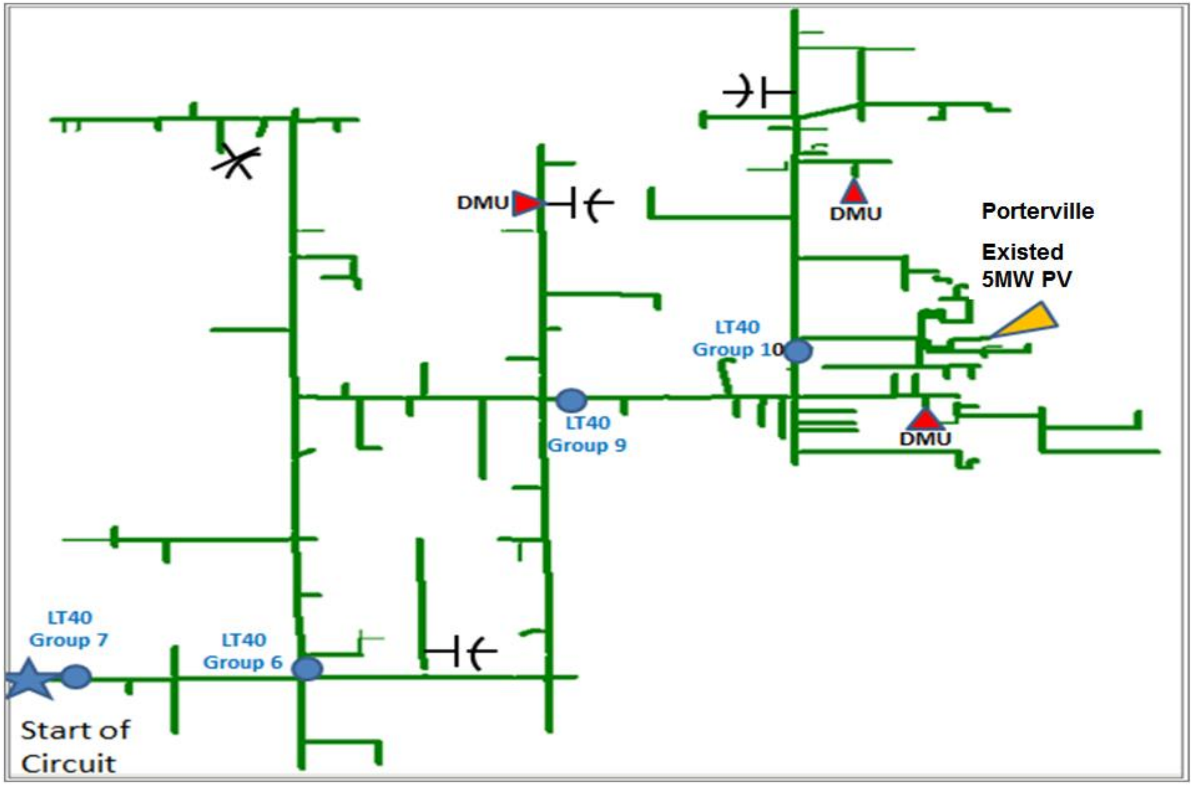
			PSCAD	OpenDSS					
				5s	10s	15s	30s	40s	50s
Load tap changer		Max	5	6	5	5	6	5	5
		Min	4	5	5	5	5	5	5
		# of actions	1	1	0	0	1	0	0
Reg. #3	A	Max	7	6	6	6	6	6	7
		Min	4	3	3	3	3	4	4
		# of actions	7	6	7	5	8	2	7
	B	Max	4	4	4	4	4	4	4
		Min	1	2	1	1	1	2	1
		# of actions	8	5	6	5	6	2	7
	C	Max	2	2	1	1	1	1	1
		Min	-1	-1	-1	-1	-1	0	0
		# of actions	8	6	6	4	8	1	4
Cap. #1		Opening time (s)	489	495	-	-	470	-	150

See: D. Paradis, F. Katiraei and B. Mather, “Comparative analysis of time-series studies and transient simulations for impact assessment of PV integration on reduces IEEE 8500 node feeder,” IEEE PES GM, Vancouver, Canada, July, 2013

Fontana: Data Acquisition Deployment



Case Study: Porterville, CA Study Circuit

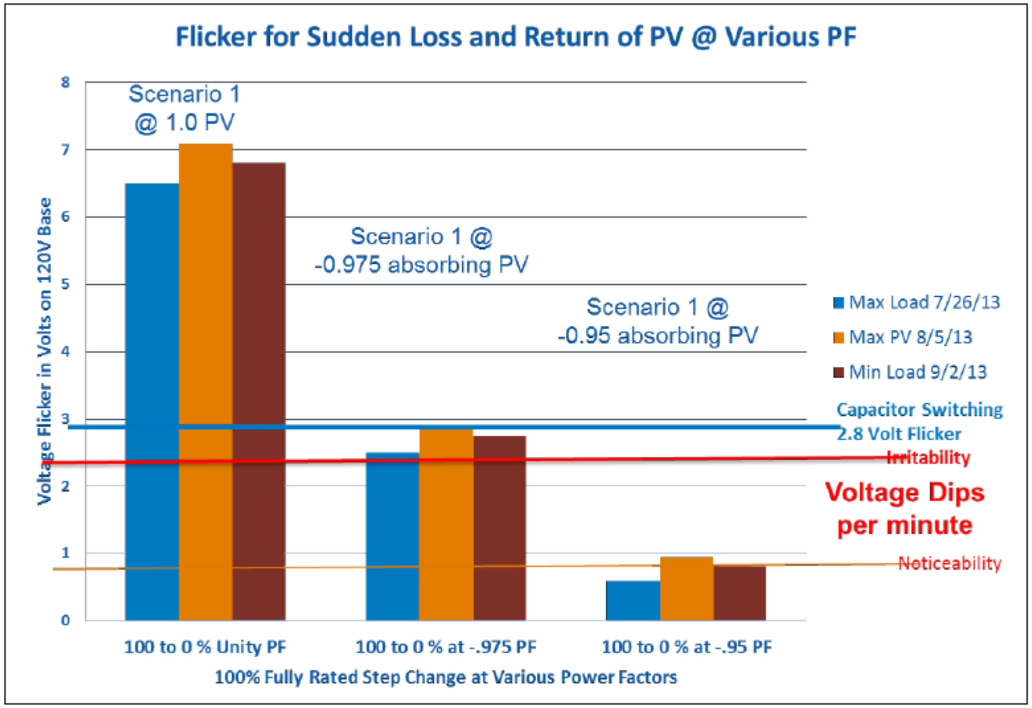


- 5 MW PV fixed-tilt system near the end of the circuit (about 7 miles from the start-of-circuit)
- Circuit is typically lightly loaded (dominated by agricultural pumping load)
- Voltage along the circuit is regulated by switched capacitors

Determining Mitigation Strategy

PV Impact Assessment Method – Expanded to Determine PV Mitigation Strategies

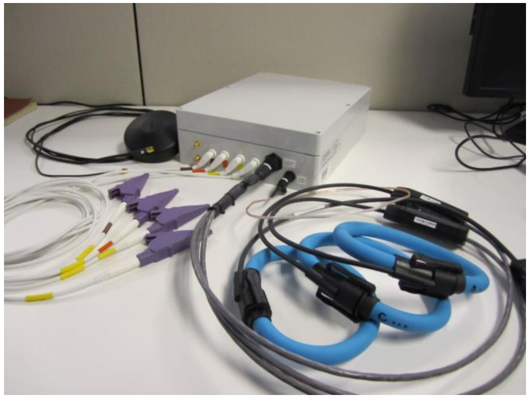
- Applied PV Impact Assessment Method (3 salient loading levels)
- Added PV mitigation measures to model and evaluated the effectiveness and "performance" cost of implementing the mitigation measure
- Tried to minimize voltage variations below "Noticeability"



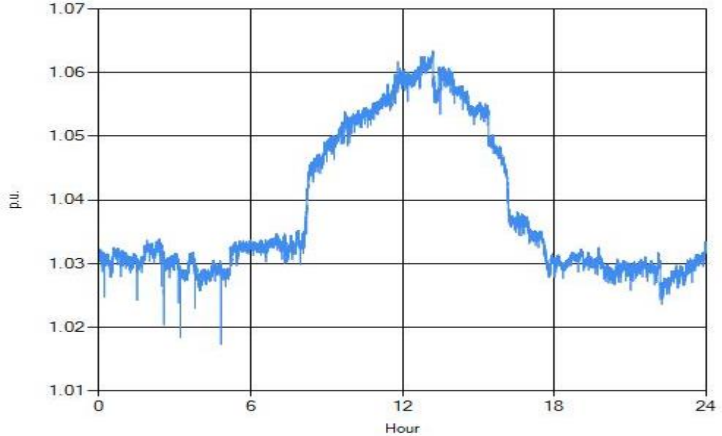
See: B. Mather, et al., *"NREL/SCE High Penetration PV Integration Project: FY13 Annual Report," NREL Tech. Report TP-5D00-61269, June, 2014.*

Field Measurements Show Impact

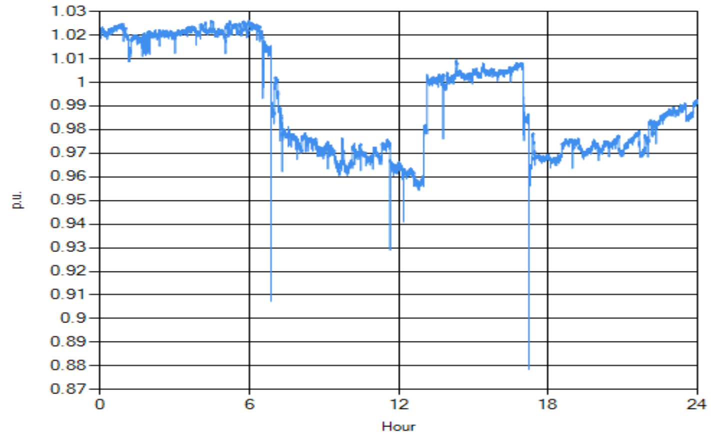
Validated PV assessment method using PV impacts measured on the study circuit



Voltage near PV system – Mostly Sunny Day



Voltage near PV system – PV Offline



See: F. Katiraei, B. Mather, A. Momeni, L. Yi, and G. Sanchez, “Field Verification and Data Analysis of High Penetration Impacts on Distribution Systems,” in proc. of IEEE Photovolt. Spec. Conf., New Orleans, LA, July, 2015

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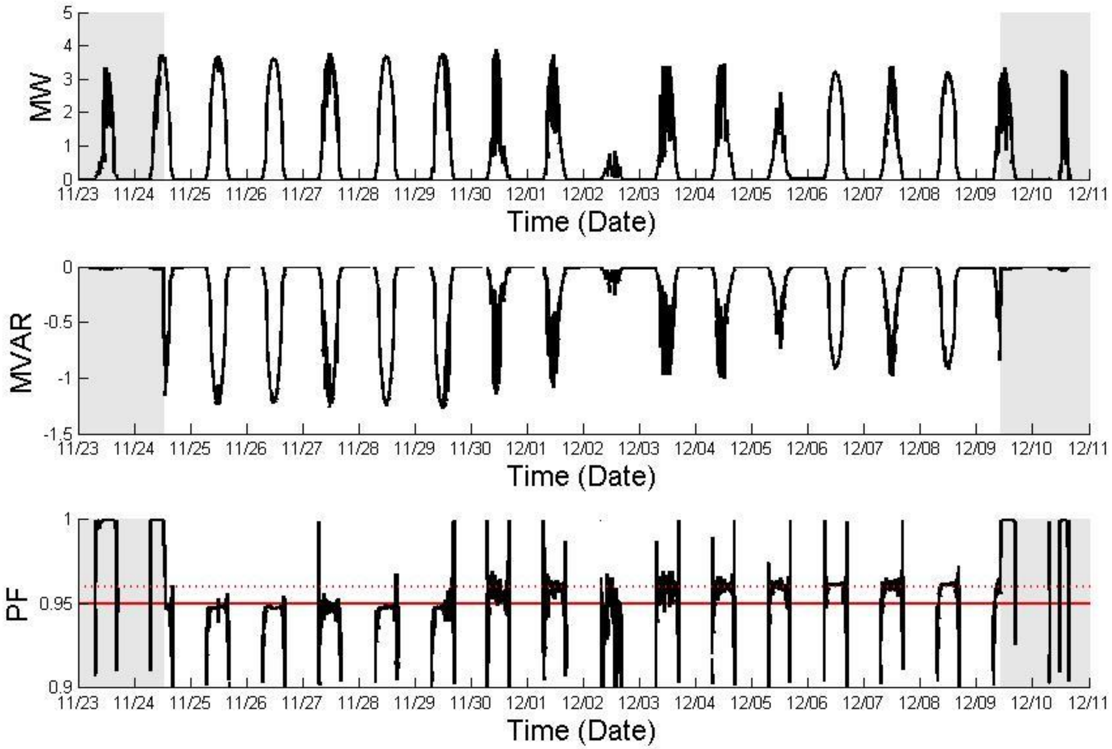
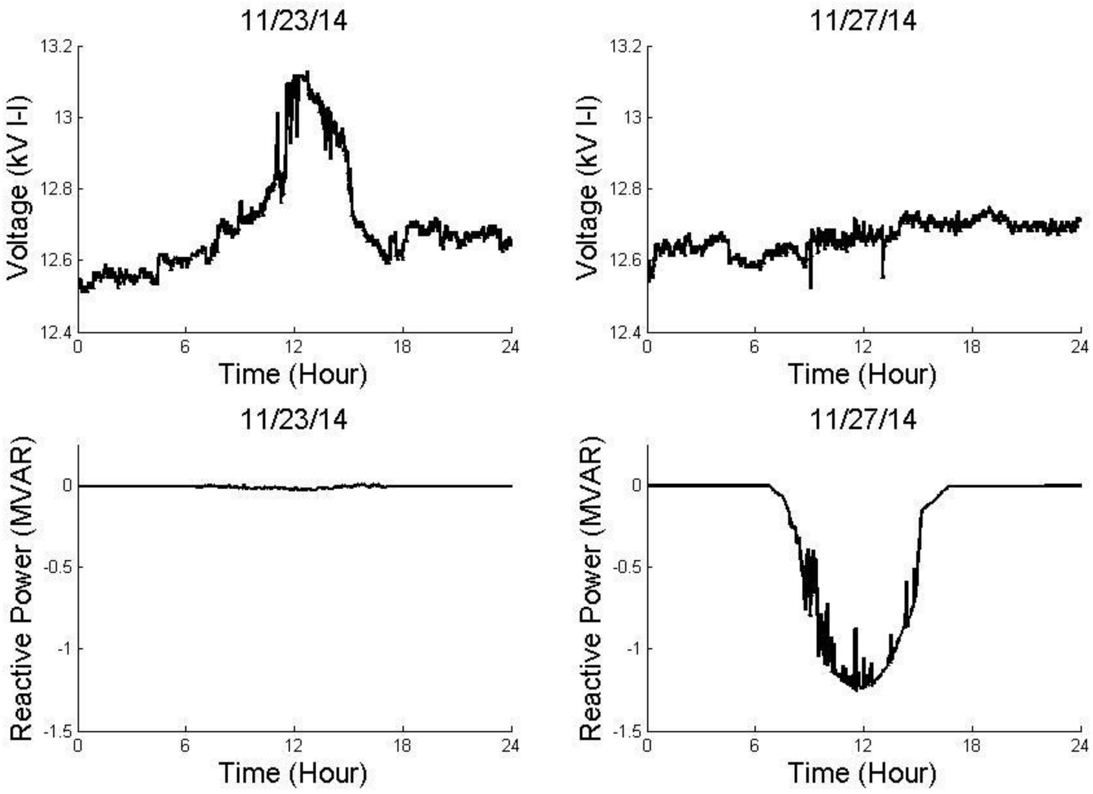
Demonstration of Adv. Functionality Ability



- All 10 PV inverters were adjusted to operate at an inductive power factor of 0.95.
- On the 5th day of the demonstration 2 inverters reverted to unity power factor operation (reasons unclear)

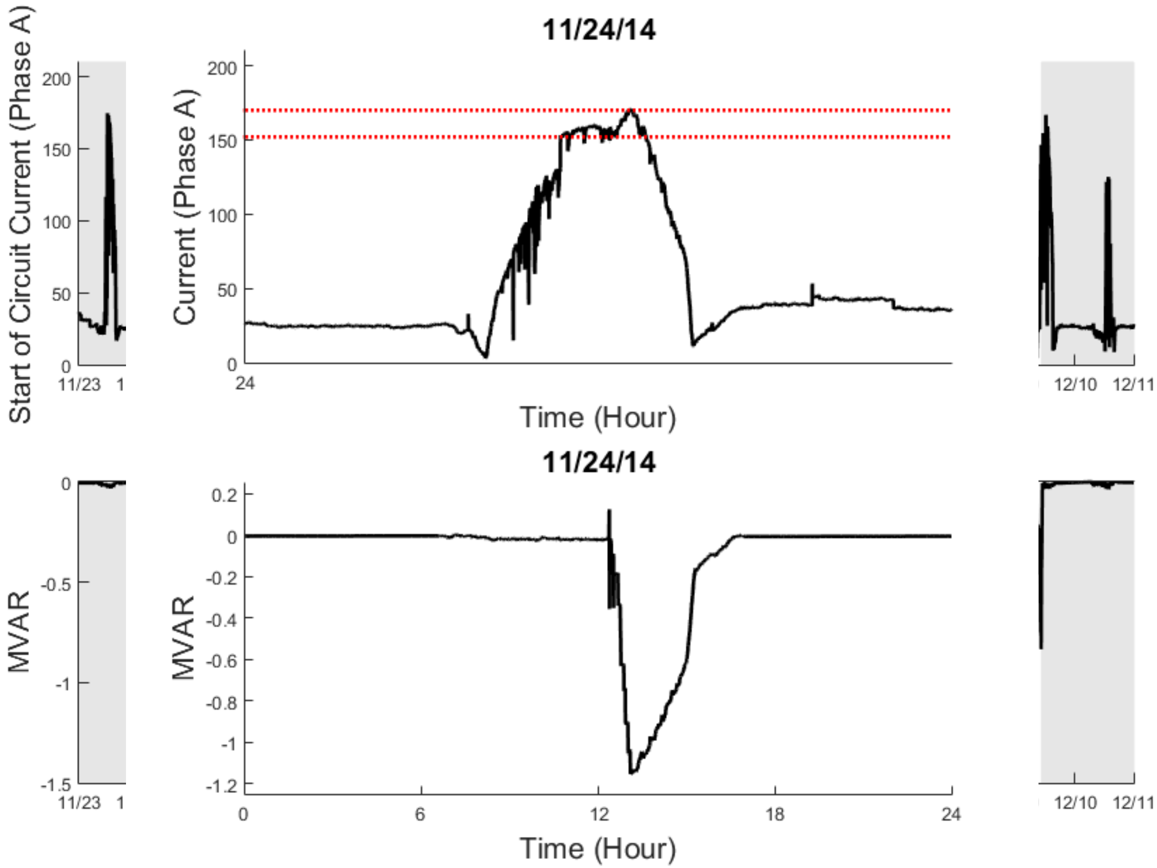
See: B. Mather, A. Gebeheyu, “Field Demonstration of Using Advanced PV Inverter Functionality to Mitigate the Impacts of High-Penetration PV Grid Integration on the Distribution System,” in proc. of IEEE Photovolt. Spec. Conf., New Orleans, LA, July, 2015.

Demonstration of Voltage Impact Mitigation



- During the demonstration period voltage at the PV system's interconnection was less variable.
- Voltage is about 400 V lower or 0.03 per unit.

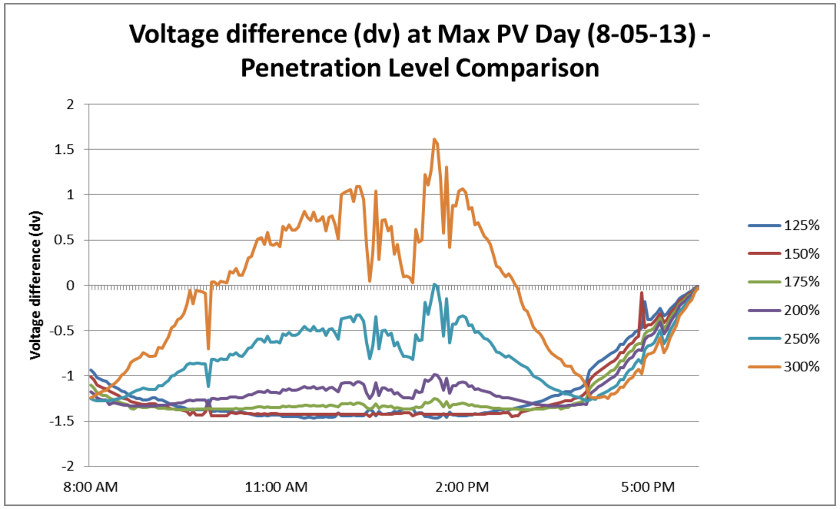
Impact of Mitigation – Reactive Current

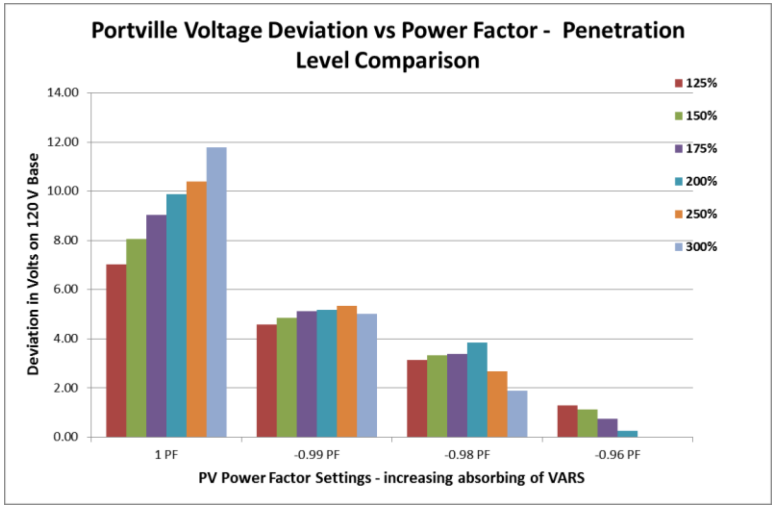


- During the demonstration period current (magnitude) at the start-of-circuit is higher due to reactive current flows.
- Additional current on the circuit is modest.
- Mitigation technique seems compatible with voltage control scheme.
- Allows aggregation of variable reactive current flows at sub-trans./trans. sys,

Looking forward – What to expect next

This study looked at what distribution-system-level impacts should be expected at even higher rates of PV penetration (up to 300%)



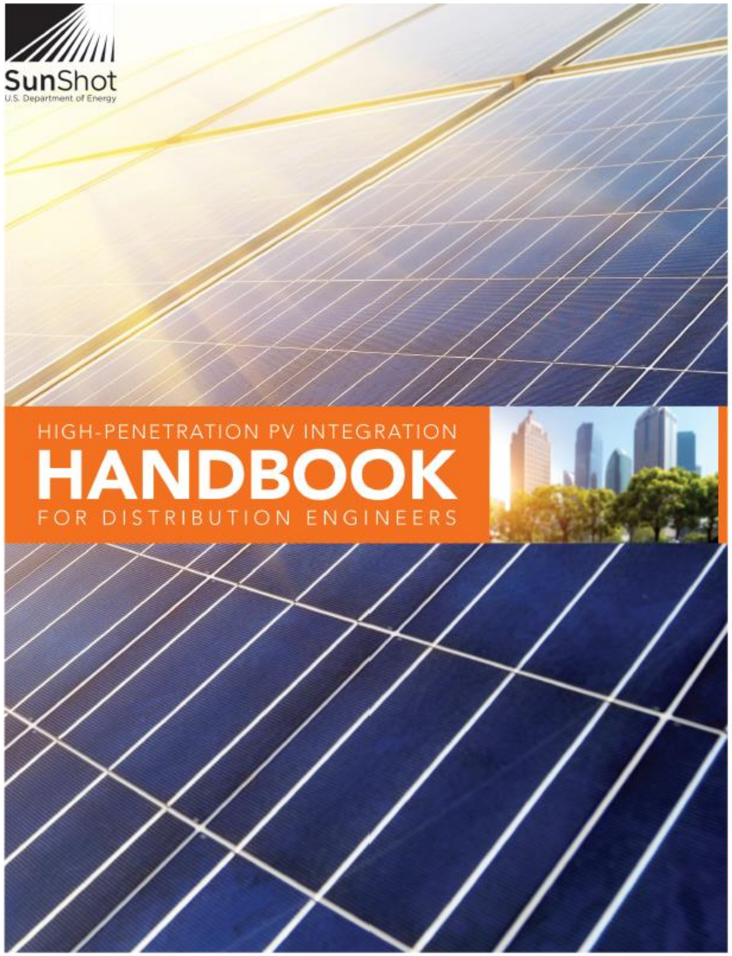


Study findings (generally stated):

- Impact types remain the same – voltage is still dominant impact
- Mitigation becomes more complicated
- 100% loss and return assumptions become increasingly conservative

See: D. Cheng, B. Mather, R. Seguin, J. Hambrick, R. Broadwater, "PV Impact Assessment for Very High Penetration Levels," in proc. of IEEE Photovolt. Spec. Conf., New Orleans, LA, July, 2015.

High Penetration PV Integration Handbook



Developed under the auspices of the NREL/SCE Hi-Pen PV Integration Project Specifically for Distribution Engineers:

- Condensing the experience gained and research results of the entire project into a handbook for use by distribution engineers facing hi-pen integration challenges in their service territories
- Research expanded to include utility practices and operations beyond just SCE's current practices and operations (i.e. using capacitors as their sole method of voltage regulation)
- Reviewed by practicing distribution engineer experts working on PV interconnection

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